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Land Use Changes and Their Impacts on the Vegetation Kromme River Peat Basin, South Africa

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ABSTRACT

This study examined plant diversity status and the impact of drivers of change on the Kromme Peatlands in 2006. Species diversity was assessed using Whittaker plots. Ordination techniques were applied to determine species-environment relationship. Land use dynamics were assessed using GIS techniques on orthorectified images. Six peat basins were subjectively classified into good, medium and poor condition peat classes. This classification was based on the extent of disturbance on the vegetation. In the good peat basin (Krugersland), the vegetation was mostly diverse (4.1 Shannon's mean index) followed by medium class (Kammiesbos) (3.8 Shannon mean index) and poor class (Companjesdrift) (2.5 Shannon mean index). Species were not evenly distributed, since 77.8% of the Shannon's evenness index was < 1. There were variations in species richness. Species distribution and composition were influenced by grazing intensity, alien invasive, K, P and Ca^{2+}. Total species variance accounted for first two axes was 40.7%. Analysis of images showed a progressive decrease in Peatland between 1942 (5.3%) and 1969 (8.3%) in the good and poor classes, with marginal increase from 1969 (1.5%) to 2003 (4.1%). Annual net rate of change over 61 years was -0.32% and -0.79% respectively. Invasive species in Peatlands increased by 50% between 1942 and 2003. Yearly net rate of change was +0.82% (good class) and +1.63% (poor class). Conservation measures such as clearing of alien invasive species, grazing regulation, construction of gabions (to in improve ground water infiltration, uplifting water table, as well as mitigate the extent of damage caused by floods) in 2003, helped reclaimed large parts of the peat basin that were lost. The continuous implementation of these conservation measures, could greatly improve on the functional status of the peat basin, especially as a carbon sink.

KEYWORDS: Peat lands, species richness, diversity, condition class, species invasion, CCA, Cluster analysis

INTRODUCTION

Peat is sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material (IMCG Global Peatland Database). Grundling et al. (2004) defines peat as a brownish-black organic soil that is formed mostly in acidic, anaerobic wetland conditions, and comprises partially decomposed, loosely compacted organic matter. The importance of peatlands especially as carbon sinks, has been recognised by the European Union, and has subsequently identified a number of bogs as priority habitats for conservation under the Habitats and Species Directive (Wildlifetrust.org.uk). About 11 peatland eco-regions have been identified in South Africa (Marneweck et al. 2001).The Kromme peat basin is formed from palmiet-fen and are used for pasture and orchard farming. Ins pite of their importance, peatlands are reportedly threatened through erosion (Grundling et al. 1998), fire (Grundling et al. 1999) and alien vegetation (Haigh et al. 2002). Grobler et al. (2004) revealed that anthropogenic disturbances such as crop cultivation, fire, peat drainage, and the cutting/clearing of natural vegetation, have rapidly dwindled the once pristine peat swamp forest in the Kosi Bay Lake system in South Africa. The overexploitation of certain species, the introduction of exotic species, and the pollution or toxification of the soil, water and atmosphere have had major effects on South Africa's terrestrial, freshwater and marine biodiversity (White Paper on South Africa's Biological Diversity, 1997).

Historically, the Kromme River land users changed from being predominantly pastoralists to commercial orchard farmers from about 1775 until present times (Haigh et al. 2002). More than 60% of the wetland catchment has been damaged beyond repair due to agriculture, channel and bank erosion and the proliferation of alien vegetation at the expense of conservation and rehabilitation (Natural Bridge Communications, 2005).

This research work therefore attempts primarily to investigate the extent of the threat to plant diversity, emanating from anthropogenic activities and natural causes that the Kromme River Peatland Complex is experiencing and to suggest possible measures of restoring its natural functioning status. The study also seeks to find baseline information on the plant diversity potential of the wetland.

MATERIALS AND METHODS

Study area

The Kromme River drains the Kouga Mountains eastern part of the inter-montane valley within the Cape Fold Belt, following a long inter-montane valley around the town of Kareedouw, and flows eastwards into the Indian Ocean west of Humansdorp at St. Francis Bay. The proposed study area is located between latitudes 33° 55` S and 33° 59` 15`` S, and longitudes 24° 15` E and 24° 26` 20`` E above the Churchill Dam (34° 05` S and 24° 29` E) (Figure i). The 48 km long peatland complex is situated upstream of the Churchill Dam, around the town of Kareedouw in the Eastern Cape Province. The altitude of the upstream basin is in the range of 350 to 300 m above mean sea level, with an average slope of 0.6% (Haigh et al. 2002). The geology of the area is dominated by quartzites and granites of the Cape Supergroup. The Kouga Formation (300 to 400 m) follows distinctive white quartzitic sandstone, with subordinate shale horizons forming the bedrock of the Kromme River basin. The predominant soil type is dark organic-rich loam within the

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immediate vicinity of the peat basin. Additionally there are alluvial soils and lighter structure less unconsolidated sandy soils along the course of the wetland (Haigh et al. 2002). The general climate in the Southern Cape region and in particular the Kromme Catchment, exhibits a bimodal pattern with spring and autumn generally the wetter periods. The western part of the Kromme River basin has an average annual rainfall of 500-800 mm. The entire catchment experiences occasional flooding. The Kromme Catchment vegetation is primarily a mixture of grassy and mountain fynbos. The dominant vegetation of the peat basin is palmiet (*Prionium serratum*) with smaller areas of grasses, reeds, sedges and ferns.

Vegetation sampling techniques

Apart from Krugersland peat basin, which was predominantly palmiet species, the rest of the five peat basins were similar in community structure and composition. So we classified the six peat basins (valley floor marsh) into three different condition classes based on the state of vegetation cover and severity of land disturbance along an environmental gradient. This includes good condition class (Krugersland and Hudsonvale peat basins), medium condition class (Kammiesbos and Kareedouw peat basins) and poor condition class (Companjesdrift and Hendrikskraal peat basins).

The Modified-Whittaker nested vegetation sampling method was used for plant data collection on bi-monthly, on each peat basin, from January to December 2006. The Modified-Whittaker nested plot is a vegetation sampling design that is used to assess plant communities at multiple scales (Stohlgren et al. 1995). Twenty four Modified-Whittaker georeferenced plots were randomly located in six peat basins according to their designated condition class, from west to east. The plot measures 20 m x 50 m (1000 m^2) and contains nested subplots of three different sizes. A 5 m x 20 m (100- m^2) subplot is placed in the plot's center; two 2 m x 5 m (10 m^2) subplots placed in opposite corners of the plot and a total of ten 0.5 m x 2 m (1 m^2) subplots. Plots are laid parallel to the major environmental gradient of the vegetation type being sampled to encompass the most heterogeneity (Stolhgren et al. 1995). All the plot locations were at 33° 52.589`S, 24° 02. 843E (Krugersland), 33° 53. 059`S, 24° 04.231E (Companjesdrift), 33° 53.802`S, 024° 07. 207E (Hendrikskraal), 33° 54. 294`S, 24° 08.580E (Kammiesbos), 33° 54. 298`S, 24°10.592E (Hudsonvale) and 33° 56.168`S, 24° 17.038E (Kareedouw) (Figure i). The Modified-Whittaker technique (1) reduces bias and under-reporting of species richness due to spatial auto-correlation and (2) detects more and unique species per plot compared to both intensive and extensive plot design type (Stohlgren et al. 1999; Barnett and Stolhgren, 2002).

All vascular plant species were identified to species level where possible, and estimated for percentage ground cover. Each species was estimated and recorded in the 1 m^2 subplots, using the Domin-Krajina cover abundance scale (Mueller-Dombois and Ellenberg, 1974). The peat basins were distributed over a distance of approximately 38km, and are 3-4km apart. Some plant species were identified in the field with the aid of literature such as (Pooley 1998) and (van Oudtshoorn 1999). Plant specimens that were difficult to identify were preserved in a plant press and taken to the herbarium at the Schonland herbarium for identification. Prior to plant identification, samples were dried to a recommended temperature within three days of collection and transferred to a freezer for a period of 48 hours. Most plant insects are killed during freezing, thus plant samples could be preserved for longer periods when stored, without being destroyed by insects.

Assessment of environmental variables

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Assessment of environmental variables was undertaken to determine the extent of its influence on species composition and distribution. This was done by correlating all plant species sampled with environmental variables and compared among the six peat basins. Eleven soil fertility variables, plus erosion and grazing intensity were assessed. Twenty four (24) 500g soil samples were randomly collected from each Modified-Whittaker plot at a depth of about 10cm and analyzed for their macro/micro elements such as total nitrogen, potassium, phosphorus, calcium, aluminium and zinc, pH, organic carbon concentration and total cation and acid saturation. Analyses were carried out in line with the standard methods and guidelines of the Manual of soil analysis methods (1974) at the Döhne Analytical Laboratory, Stutterheim- South Africa. Since plant roots occupy a certain volume of soil, the volumetric method (known as scooping) was adopted as opposed to the more conventionally used mass method. The procedure for scooping is standardized and it has been found that the inherent error caused by scooping instead of weighing is about 1% which is insignificant considering the amount of time saved (Ras et al. 2002). Soil samples were initially spread evenly on a drying tray at an oven temperature of 50 to 60° C, after which they were grinded by a motorized roller-type grinder.

Macro elements such as phosphorus, potassium, calcium and magnesium were determine by atomic absorption spectroscopy (AAS) techniques, using AMBIC -2 extract method developed by Murphy and Riley (1962); Van der Merwe et al. (1984). A 2.5 ml soil was put into a shaker tube and dispenses 25 ml AMBIC extracting solution. A 1 level spatula activated charcoal was added to the sample and dispenses with 25 ml AMBIC extracting solution. The extracts was then Shaken for 30 minutes at 20° C and later filtered into a clean sample cup through Whatman no. 42; 9 cm folded filter papers. Phosphorus availability was determined by Molybdenum blue-ascobic acid techniques, using AMBIC-2 method. The colorimetric determination of extracted P is based on the reaction of orthophosphate with ammonium molybdate and potassium antimony titrates in an ascorbic acid medium to form an antimony-phosphomolybdate complex (Van der Merwe et al. 1984). A standard sample solution of 2 ml, blank and the sample extract are mixed into a sample cup and dispense with 18 ml of dilute color developer into each cup. The solutions are allowed to stand for 40 minutes and the absorbance read at 660 nm with the spectrophotometer adjusted to zero absorbance with the blank.

Soil pH value was measured in 1mol dm^{-3} KCl solution and stir for 10 minutes. Suspension was allowed to stand for 1 hour before pH is determined in an electrode positioned in an automatic titrater-pH meter combination (Ras et al. 2002). Determination of organic carbon was carried out using the Walkley-Black method. A 10 ml Potassium diccromate ($K_2Cr_2O_7$) was added to a 0.5 g of soil and placed into a 500 ml Erlenmeyer flask. The flask is allowed to swirl to disperse the soil in the solution, by adding 20 ml concentrated sulphuric acid. A 150 ml water, 10 ml ortho-phosphoric acid and 10 drops indicator solution, was added after cooling the soil solution for 30 minutes. The excess dichromate with iron (II) ammonium sulphate solution is titrated to a the endpoint where the color changes to green (Walkley and Black, 1934; Walkley, 1947)

Grazing intensity was assessed per peat basin based on the extent of the grazed area and exposure of the soil surface. A field scoring sheet was used in which administered. 1 = severely grazed; 2-3 = moderately grazed and 4-5 = slightly or not grazed area. Erosion intensity was scored, using a range of 1-5. This was done based on the extent of area eroded and severity. For example severe gully erosion affecting more than half of the area sampled, was scored 5, sample plots moderately eroded = 3-4 and areas less eroded with reasonable amount of vegetation= 1-2. A field description of the major erosional features across the six peat basins was carried out, following van Zuidam (1986) and Gregg (2005). Four different types of erosion were identified. They included: 1. fluvial erosion- this occurs when running water gouges shallow channels or deep gullies into the soil; 2. gully erosion occurs on unconsolidated subsoils, generally deep and generate a lot of sediment, which transported into rivers; 3. rill erosion- occurs on sloping land, especially on cultivated fields, where water run-off may gather in small V-shaped channels or rills and 3. stream bank erosion especially in rivers and watercourses experiencing periodic flooding.

Analysis of aerial photograph of land use dynamics

Aerial photographs of the study area were obtained from the department of Survey and Mapping, Cape Town, South Africa. Only available images that cover the catchment area were considered for land use change analysis. Aerial photos from 1942, 1954, 1969 and 1986, covering the largest peat basins were geo-rectified in order to prepare them for a comparison with 2003 colour aerial photographs. These images were used to compare with the 2003 colour aerial photographs which had been orthorectified by Surveys and Mapping. All images previously in analogue form were scanned onto compact disc (CD) in JPEG and TIFF image formats. Orthorectification and georeferencing of images were performed using TNTmips 7.2 from MicroImages Inc (http://www.microimages.com). Onscreen digitizing of aerial images was carried out with the aid of Manifold Systems version 7x (http://www.manifold.net) to ascertain the changes on the marsh, riparian zones and floodplains. Transformed areas were quantified and the remaining hard copies and digital photographs that were not geo-rectified were visually assessed. Hard copies obtained from Surveys and Mapping was of higher quality compared to scanned images, especially those of 1954. These were inspected and corroborated with scanned images for detailed features. Rainfall records before the date of each photograph were noted, since these photographs were taken after heavy flood occurrence in the respective years. So we only commented on the impact that the floods may have contributed in the loss of the peat basin, in the discussion section. For general classification of the state of marsh conditions across the peat basins (as a result of changes over the investigative period), both hard copies and scanned geo-rectified images were used. Hard copies were studied with the aid of a parallax bar and stereoscope. The selected aerial photographs of 1942, 1954, 1969 and 1986 consistently captured about three-quarters of the total land-cover of the study area throughout the years mentioned above. Both Krugersland and Companjesdrift peat basins were selected for detailed analysis of changes in peatland area (in hectares) since they constitute the greater portion of the entire peatland catchment, with historical land use activities and available high quality geo-rectified images for 1954, 1969 and 2003 (Figure ii). Aerial photographs of 1942 and 1986 were not used for detail analysis.

For the detailed study of deterioration, Companjesdrift basin 2, below the weir, was considered. To compare changes in channel size from both aerial photos and orthorectified images, a 2D Piecewise Affine model was employed to resample aerial photographs to fit into the orthophoto projected space. Aerial images of 1969 (the poorest quality) were used as the baseline to identify the stretch of the channel where information was available for all three years (1954, 1969 and 2003). The images of the other two channels were overlaid. This was followed by a splitting of the 1954 and 2003 channel polygons, using the northern and southern limits of the 1969 channel polygon (i.e. extending a line across the polygons from 1969 to 1954 and 2003), to determine the extent and changes of the erosion channels in these three time periods. The marshes were classified according to functionality (i.e. permanent or seasonal zones or floodplain). The riparian zones were classified only when distinct in character from the edge of the river channel or very steep due to erosion. For the purpose of this land use analysis, lands considered as 'transformed' include orchards, pasture farms -e.g., palatable Kikuyu grass (*Pennisetum clandestinum*) and areas cleared, but formerly covered with exotic species) and cultivated or previously cultivated lands.

Annual net rates (ANR) of change in peatland size and area invaded by alien species in any two of the aerial photographs were obtained by calculating the differences in mean hectares (between 1942 and 2003) (Table 1b) and dividing this by the number of years separating the aerial photographs.

STATISTICAL ANALYSES OF VEGETATION AND ENVIRONMENTAL RELATIONSHIP

Vegetation

Both ordination (Canonical correspondence analysis) and inordination techniques (cluster analysis) were used to determine the pattern and distribution of community structure and composition, as well as their relationship with environmental variables. Complete-linkage clustering (furthest neighbour method) was applied to cluster individuals or group of plant species of similar ground cover among sample plots in all six peat basins. This method looks for the most similar pair, and further fusions depend on finding the minimum distance between the furthest points in existing groups of Whittaker plots (Sneath and Sokal, 1973). The degree of matching between each pair of

Whittaker plots was computed on the basis of similarity of species cover using the coefficient of squared Euclidean distance (Crowford and Wishart, 1967; Noest and Van der Maarel, 1989). Only 1 m2 sub-plots all 24 Whittaker plots, were entered into Community analysis package (CAP) version 1.41 (Henderson and Seaby, 1999) for similarity analysis. Canonical correspondence analysis (CCA) (terBraak, 1986) was performed to examine the relationship between plant species distribution and associated environmental gradients or variables only on 1 m2 sub-plots, using the Environmental community analysis version 1.3 (ECOM.exe) (Henderson and Seaby, 2000). Shannon-Weiner Diversity Index was applied to assess species diversity per sample plot, as was recorded from the respective peat basins. Below is the Shannon-Weiner Diversity index:

$$\text{Diversity } (H') = -\sum_{i=1}^{s} P_i \ln P_i$$

where s = number of species

P_i = proportion of individuals or the abundance of the ith species expressed as a proportion of the total cover

ln = natural logarithm

The index makes an assumption that (1) individuals are randomly sampled from an 'infinitely large' population and (2) all the species from a community are included in the sample. Also, values for the diversity index usually lie between 1.5 and 3.5, with exceptional cases of values exceeding 4.5 (Kent and Coker, 1992). With the above assumption of Shannon-Weiner's index, one Whittaker plot of three different sub-plots (10 m^2, 100 m^2 and 1000 m^2), each from the three condition classes (good, medium and poor condition peat basins) (Table 1b) was randomly sampled and the species diversity calculated. A One-way-ANOVA test was applied to test for the differences in species diversity/evenness and species richness from one peat basin to the other, using Statistica version 7.

Species relative abundance (evenness or equitability) was also computed using Shannon-Weiner index diversity model below:

$$\text{Equitability (J) (evenness)} = \frac{H'}{H'_{max}}$$

Where s = the number of species

p_i = the proportion of individuals of the ith species or the abundance of the ith species expressed as a proportion of total cover

ln = natural logarithm

RESULTS

Status of the plant communities, species richness and diversity of the Kromme River Peatland

Out of the 24 entered for similarity analysis, cluster results showed that six Whittaker plots from the poor peat basins were grouped together, instead of eight plots. This is because, the remaining two Whittaker plots were grouped among the 16 Whittaker plots in good and medium peat basins; bringing the total to 18 Whittaker plots. Hierarchical cluster analysis separated sample plots into five distinct clusters or groups across the six peat basins, based on variations in peat condition type along an environmental gradient (Figures 2 & 3). Plant species recorded in these five clustered plots fell under three major identified communities. They included: (a) the fringing forest of the riparian zones; (b) the fen and palmiet plant communities of the valley floor marsh and (c) the grassy fynbos plant communities of the floodplains. A total of 65 different plant species were recorded, of which 23% were indigenous wetland plants (e.g. *Cyperus denudatus, Juncus lomotophyllus, Nymphaea nouchali, Thelypterus sp, Prionium serratum, Phragmites australis, Paspalum dilatatum*), 15.4% constituted exotic woody and grass species (e.g., *Eucalyptus grandis, Acacia cyclops and Acacia mearnsii,* and *Hypochaeris radicata)* and the remaining 61.6% represented indigenous non-wetland plant species.

Plant species in cluster 1 were predominantly grassy-fynbos and riparian communities and associated with poor condition floodplain valley floor marshes of Companjesdrift and Hendrikskraal (figure 2). CCA ordination along axis 1showed that species composition in these peat basins strongly correlated with erosional features (e.g., eroded channels, and stream bank erosion) and overgrazing, followed by magnesium and pH. Phosphorus concentration appeared to be of less significance in explaining variation in floristic composition. Plant species common in these transformed peat basins were predominantly alien invasive species and sparsely distributed (e.g., *Conyza albida, Acacia mearnsii* and *Hypochaeris radicata*). Species richness was low in both Companjesdrift (22.5 ± 8.9) and Hendrikskraal (22.3 ± 7.0) peat basins. Species diversity was equally low (2.5 Shannon index) (Table 1a & b).

Clusters 2, 3, 4 and 5, were associated with both good and medium condition peat classes of Krugersland, Hudsonvale, Kammiesbos and Kareedouw respectively (Figure 2). Even though these peat basins were in moderate to good condition, there were isolated boulders in some plots and remnants of burnt vegetation. While Krugersland and Hudsonvale peat basins were confined within the permanent wet zone of the valley floor marsh, with characteristic heavy dark-brown soils, Kammiesbos and Kareedouw peat basins were located in the seasonal zone of the peat valley floor marsh (Figure 2). Fen and palmiet plant communities constituted the floristic compositions of Krugersland and Hudsonvale peat basins (e.g., *Thelypteris sp and Prionium serratum)*, with fewer species from the families of graminae (e.g., *Pennisetum macrourum)* and cyperaceae (e.g.,*Cyperus denudatus*) present. Species composition in Kammiesbos and Kareedouw peat basins typical indigenous wetland plants (e.g., *Prionium serratum and Phragmites australis)* and non-wetland plants (e.g., *Stoebe sp)*, with some pockets of fynbos communities (e.g., *Rhus rehmaniana* and *Rhus dentata)*. CCA ordination showed that the observed species in the wet permanent and seasonal zones of the peat basins were largely influenced by Potassium and calcium concentration, as species positively correlated with these macro elements along axis 1 and axis 2. Species-environment correlation was high (axis 1 = 0.70 and axis 2 = 0.96) across the six peat basins. This reflected in the relative contribution of each species/environmental variable (canonical eigenvalues for axis 1 = 0.92 and axis 2 = 0.40). The first two axes accounted for 53.9% of community variance in all 24 Whittaker plots entered for CCA analysis.

Species turn over for both the good classes of Krugersland (32.5 ± 3.4) and Hudsonvale (25.8 ± 8.0) were high, with the same trend recorded in species diversity (4.1 Shannon index). Species richness in the medium condition peat basins of Kammiesbos (26.5 ± 9.0) and Kareedouw (24 ± 7.3) were relatively high with 3.8 Shannon diversity index. Species richness ($p = 0.0008$, $F = 1241.6$, $df = 4$) and diversity ($P > 0.20$; $F = 11.04$; $df = 2$) differed in the good, medium and poor condition peat basins. Though species diversity was high, they were not evenly distributed across the six peat basins ($P > 0.21$; $F = 0.94$; $df = 2$). Seven out of the nine sample plots had 77.8% of Shannon-Weiner evenness index less than one. Only two of the sample plots from good and medium and poor condition class had 22.2% of the index values greater than one (Table 1b).

Interpretation from aerial images based on the observed changes in the two biggest peat basins (Krugersland and Companjesdrift)

The observed trend in the two peat basins was one of degradation between 1942 and 1969 and a gradual improvement of its functional status between 1969 and 2003. Krugersland peat basin decreased by 5.3 % (in hectares) from 1942 to 1954 and 1.9% between 1954 and 1969 (Table 2a). However, there was a marginal increase of 1.7% of the peatland area between 1969 and 2003, with an annual net rate of change of - 0.32% over the 61 year period (Table 2b). Companjesdrift peat basin also decreased by 14.6% between 1942-1954 and a further 8.3% between 1954-1969. The clearing of the alien invasives probably contributed to a marginal increase of 4.1% in the size of the peat basin between 1969 and 2003, with a -0.79% annual net rate of change between 1942 and 2003 ((Table 2b). The area under alien invasives increased by 50% from 1942 to 2003, with a +0.82% annual net rate of change in the good condition class (Table 2a). There was a progressive increase in the area under alien invasives under poor condition class between 1942 and 1969, with a +1.63% annual net rate of change (Table 2b). All alien invasive species were cleared by 2003, explaining why there was no record in terms of area they occupied (Table 2a & b).

The relationship between community distribution and its determinants with insights from the GIS

The analysis of aerial images indicated that historical variation of the land use practices directly impacted on the pattern of community distribution across the peat basins. It can be inferred from Table 2a, b that the historical variation in land use practices (such as orchard and pasture farming) has led to a reduction in peatland area, with a subsequent increase in the area invaded by alien invasives. Observation from GIS map of 1954 (Figure 4) showed that the valley floor marsh plant community dominated by Prionium serratum, Thelypteris sp. and Phragmites australis, was virtually undisturbed, with relatively few alien invasive species and the absence of erosion and sediment deposits. However, the subsequent years saw the increases in agricultural activities, over grazing and erosion processes. These human-led activities largely influenced the changes in community distribution and composition as indicated in ordination results (Figure 3).

DISCUSSION

Plant species composition, distribution and diversity among sites

Several studies on species-environment relations have analysed the environmental determinants such as cultivation (Mensing et al. 1998), fire and herbivores (Peel et al. 2005), altitude and water depth (Ssegawa *et al.* 2004) and altitude and surface area (Rolon and Maltchik 2005) on species diversity and richness on riparian wetland vegetation and other ecosystems. In this study, Alien invasives, soil pH, potassium, phosphorus, calcium, erosion and grazing intensity were the key environmental factors that influenced the observed pattern of species distribution, composition and diversity in all sample plots as shown in CCA results (Figures iii). There were differences in species composition among the sites (poor, medium and good condition peat basins). Species composition in poor condition peat basins of Companjesdrift and Hendrikskraal clustered in group 1, were more dominated by woody alien species such as *Acacia mearnsii, Rubus cuneifolius and Conyza albida*. Indigenous wetland plants were virtually absent in most degraded sample plots in the floodplains of the peat basin, where alien species were dominant. This suggests that the presence of alien invasives appears to threaten the existence of indigenous wetland plants. The poor condition site was characterized by severe erosion and over grazing and patchiness. Crawley (1986), Pyšek et al. (1998) and Richardson et al. (2000) reported that disturbed sites are highly suitable for alien species establishment.

The less impact by environmental drivers felt in Krugersland, Hudsonvale and Kammiebos peat basins, reflected in the predominance of indigenous wetland plants such as *Prionium serratum* and *Phragmites australis*. But the heavily impacted sites such as Companjesdrift peat basin recorded low species richness (a total of 90 individuals per site, with an average of four species), whereas the good condition peat basins were highly rich in species (a total of 130 individuals per site, with an average of six different species) (Table 1a). The classification of species into different groups reflects in major differences in plant species richness and composition among sites. This is brought about by differences in the condition type in each peat basin, since the low number of species recorded was associated with sample plots located on previous farmlands and erosion hot spots. Similar studies indicated that the determinants of species richness and composition of plants in wetlands were land use (Smith and Haukos, 2002), water chemistry (Jeppesen et al. 2000; Heegaard et al. 2001; Lougheed et al. 2001) and size of the wetland (Rørslett, 1991; Vestergaard and Sand-Jensen, 2000; Oertli et al. 2002; Jones et al. 2003).

Heavy human impacts, according to Molles (1999) generally reduce the number of native species in a community while increasing the presence of alien species. These findings by the author agree with the observed pattern of species richness and composition of Kromme peat basin. The impact of drivers of change such as alien invasives, erosion and over grazing, potentially limits indigenous species richness and composition especially in the poor condition peat basins. This phenomenon, may consequently pose a threat in using the low indigenous species richness of the Kromme peat basin as a base measure in assessing typical wet-ecological conservation techniques from local to regional and national diversity. Generally, species diversity was high among the peat basins (Table 1b), since the overall diversity index obtained (1.7 to 5.8) was higher than the Shannon-Weiner diversity index that usually lie between 1.5 and 3.5 (Kent and Coker, 1992). On comparative terms, species diversity (mostly grasses), was higher in both good and medium condition peat basins (Krugersland and Kammiesbos), possibly because of less impact by anthropogenic factors (e.g., alien invasives) compared to Companjesdrift and Hendrikskraal peat basins (poor condition class) which were heavily impacted. The low presence of alien invasives from the medium and good condition sites could be attributed to the early establishment of dense stands of indigenous species over alien invasives, leading to the reduction of light penetration into the undergrowth and consequently suppressing the growth of these aliens. Other authors (e.g.,Tilman 2004) reported that studies with recent invaders suggest that, all things being equal, increasing diversity of native communities should decrease invasion success by decreasing resource availability. Using the same diversity index to assess the impact of human-induced activities on community composition, Walpole et al. (2004) also observed that open grasslands had lower Shannon-Weiner index than the denser, richer habitats in the Mara woodlands in Kenya.

Most of the areas in the good and medium peat basins were in areas that were under permanent and seasonally wet zones respectively. These zones served as a source of water for the livestock within the catchment. The highly diverse community of these peat basins partly indicates less human impact, compared to that of the poor condition peat basin that was species-poor and appeared dry during most parts of the year, due to land disturbance. It can be argued therefore that the relationship between high species diversity and the drivers of change is largely dependent on the type of vegetation community, the degree of human impact and other natural factors as well as its location on the landscape.

Although species diversity was high, it was not evenly distributed across the peat basins, indicating that plant species were evenly distributed only in peat basins (Krugersland and Kammiesbos), where the degree of impact was relatively less severe. The uneven distribution of species, typically endemic in most parts of the peat basin (e.g., palmiet plant), suggests a gradual deterioration of the natural functioning state of the peatland. This is largely attributed to the loss of the peatland through anthropogenic impacts. Haigh et al. (2002) reported of a similar annual net rate of loss of -0.31% in the Kromme peat basin, over a 58 year period (between 1942 and 2000). The observed trend of peatland loss may alter its major role as a carbon sink, to that of carbon source, thus contributing to the worsening case of global climate change.

With the introduction of the introduction of restoration activities, such clearing of alien invasive species in 2003, and the building of gabions to uplift the water table, could lead to a reversal of the peatland to its natural functioning status. This was reflected in the increase in area of peat basin from GIS analysis (Table 2a, b; Fig. 5). The International Mire Conservation Group (IMCG, 2009) reported of a gabion construction, as a restoration measure in the Southern Rietvlei peat basin in Pretoria, which was damaged by gully erosion and re-vegetation of eroded area and peat gully blocking in the Peak District National Park, North-west England.

CONCLUSION

The results of this study suggest that the Kromme peat basin was seriously under threat. This is attributed to the observed variations in community distribution, species richness and diversity in the different peatland condition classes. This was largely due to the influence of edaphic (erosion, soil pH, phosphorus, potassium and calcium), biotic factors (alien invasives) and overgrazing. These environmental variables accounted for 40.7% the explained community variation for ground cover. Transformation of the peat basins was largely due to the major drivers of change such as alien invasives, erosion, agricultural activities, over grazing and sediment deposits. However, with the introduction of conservation measures in 2003, through the clearing of alien invasive species and the construction of gabions at key points of the peat basin, helped in the gradual restoration of the peat basin. This indicates that a carefully selected restoration measure(s), tailored towards a specific impact on the peat basin (both human-led and natural drivers), could permanently help address the issue of peatland loss, considering their global importance as carbon sinks.

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TABLES

Table 1a: Species richness recorded in the 24 sample plots across the six peat basins of different condition class (i.e., good to poor class). Note that diversity was only assessed randomly on three different plots (plots A-C) and peat basins. ** This symbol denotes the different peat basins in the kromme River that diversity was assessed, whereas figures in brackets represents Shannon-Weiner index on plots A-C, mean and standard deviation

Peat basin	Plot A	B	C	D	Mean	Std.dev.
Krugersland (Good class)	28	36	32	34	32.5	3.4
Hudsonvale (Good class)	31	24	24	24	25.8	8·0
Kammiesbos(medium class)	30	26	27	23	26.5	9·0
Kareedouw (medium class)	22	23	25	26	24	7.3
Companjesdr ift (poor class)	20	20	26	24	22.5	8.9
Hendrikskraal (Poor class)	25	20	26	18	22.3	7·0

Table 1b: Results of plant community distribution analysis, showing diversity index values and mean for good, medium and poor peat basin condition classes (P= 0.20; F = 11.04; df = 2). Note that diversity was only assessed randomly on three different plots (Whittaker plots A-C) in three peat basins, following the assumption proposed by (Kent and Coker, 1992) in Shannon-Weiner's index

Peat condition type	**Shannon-Weiner Diversity index values**	**Mean diversity index**	**Std. Dev.**
Krugersland (good class)	Plot A= 3 Plot B = 3.6 Plot C = 5.8	4.1	1.47
Kammiesbos (medium class)	Plot A= 1.9 Plot B= 4.1 Plot C= 5.4	3.8	1.76
Companjesdrift (poor class)	Plot A= 1.9 Plot B= 1.7 Plot C= 3.98	2.5	1.26

Table 2a: Observed changes on the two biggest marsh peat basins (Krugersland and Companjesdrift) impacted by agents of land transformation between 1942 and 2003 as measured from aerial photographs of the peatlands

Year	Size of intact peat basin (ha)	Size of invaded area (ha)	Other transformation agents (including agricultural activities)
1942	77	4	………..
1954	63	5	Pasture and orchard farm
1969	58	9	Erosion, sediment deposits and pasture
2003	62	6	Orchard farms, drainage and erosion
Annual net rate Of change over 61year period (%)	-0·32	+0·82	

Table 2b: b. Companjesdrift peat basin (poor condition class)

Year	Size of intact peat basin (ha)	Size of invaded area (ha)	Other transformation agents (including agricultural activities)
1942	56	5	Pasture farms
1954	35	6	Pasture farms
1969	23	12	Erosion, sediment deposits and pasture
2003	23.9	0	Sediment deposits, drainage and erosion
Annual net rate Of change over 61year period (%)	-0·79	+0·63	

Figure legends

Figure 1: A map of Kromme River Peatland showing its position in South Africa as indicated by the grey arrow. The sample sites in the six peat basins are denoted by the shredded black circles. The abbreviations (PB1 to PB 6) in red colour represent peat basins

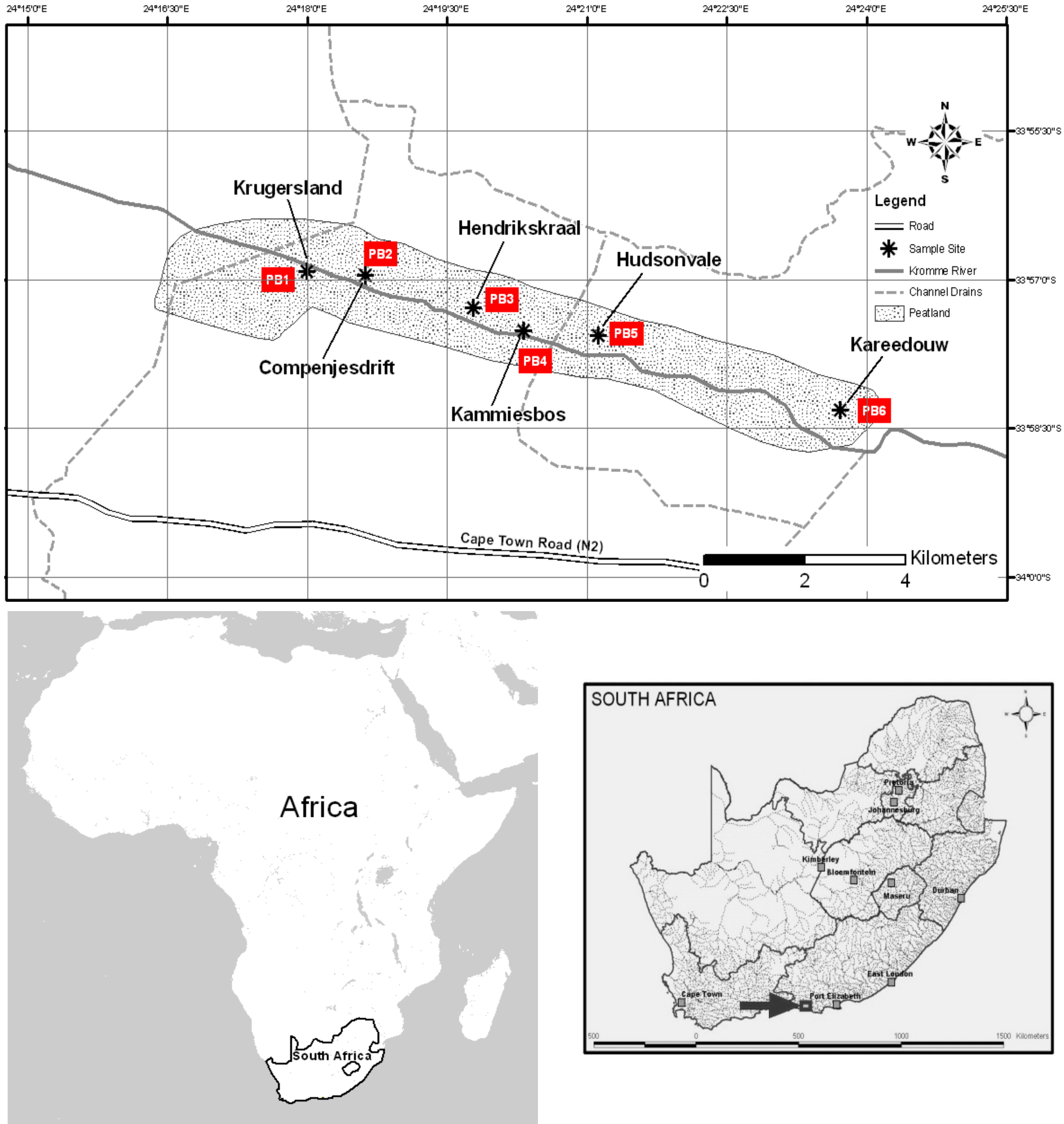

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Figure 2: Hierarchical Cluster Analysis (HCA) dendrogram showing five clusters of plant communities based on similarity in ground cover using the coefficient of squared Euclidean distances. The abbreviations denote different sample plots in the six different peat basins. Plots KA, KB, KC and KD were in Krugersland peat basin; CA, CB, CC and CD were in Companjesdrift peat basin; HNA, HNB, HNC and HND were in Hendrikskraal peat basin; KMA, KMB, KMC and KMD were in Kammiesbos peat basin; HUA, HUB, HUC and HUD were in Hudsonvale peat basin and KAA, KAB, KAC and KAD were in Kareedouw peat basin. The last letters refer to replicate (i.e. A to D). Complete linkage was used. Note the five groups of plots clustered separately

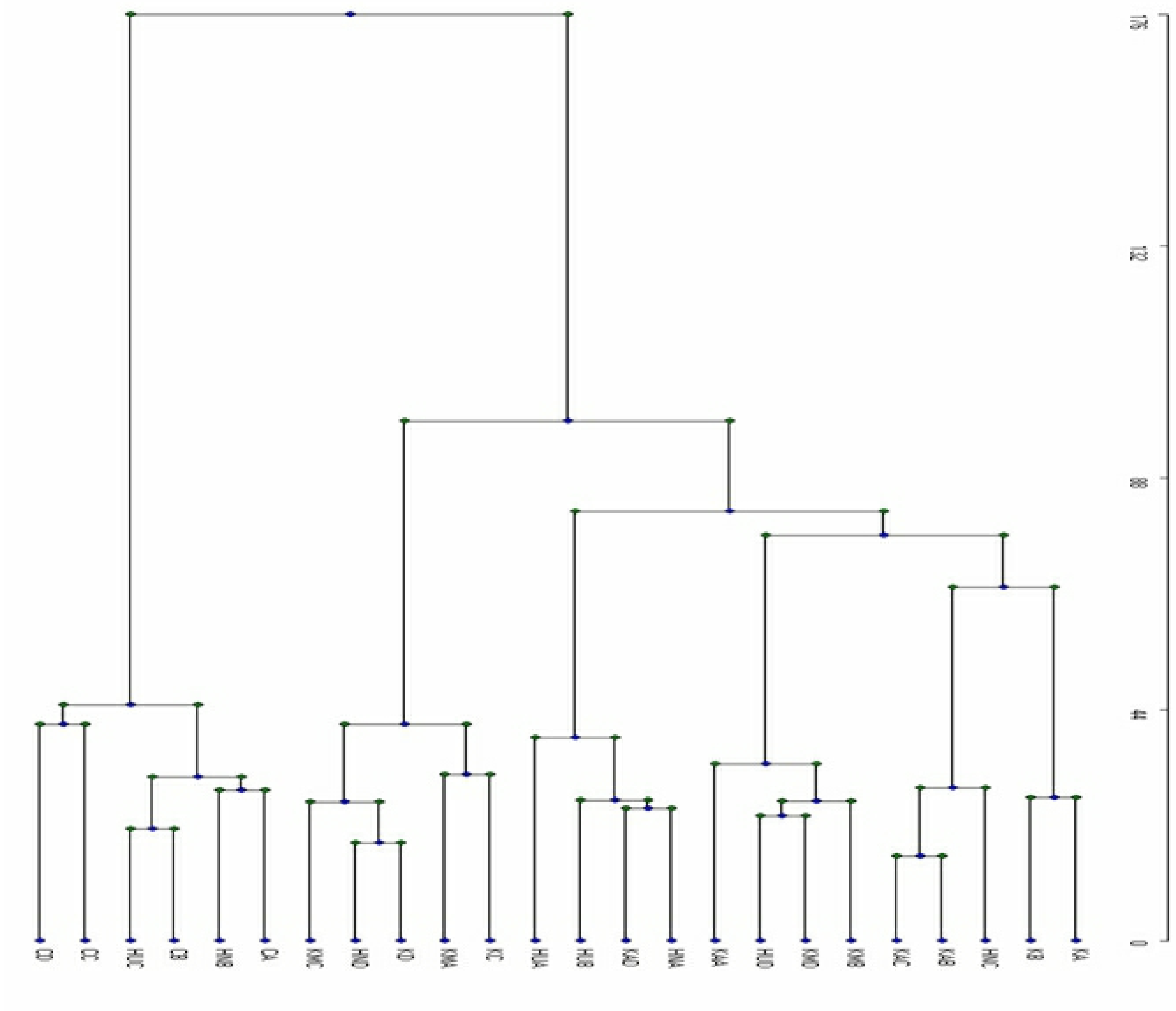

Figure 3: Canonical correspondence analysis (CCA) diagram showing the influence of edaphic factors on ground cover in the six peat basins. The squares represent sample sites, the circles represent plant species and the arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the six peat basins